Evaluation of SHADE Sun Photometer for GLOBE

Charles Haggard[1]
Dr. Margaret Pippin[2]
[1]Georgia Institute of Technology, Atlanta, GA, [2]NASA Langley Research Center, Hampton, VA

Background

Worldwide, students of Global Learning and Observation to Benefit the Environment (GLOBE) certified educators measure many different atmospheric parameters. Measurements are uploaded to the GLOBE server which is accessible to all participating GLOBE schools. A participating member can access this data and use it for classroom inquiry-based investigation. Advancements in technology such as miniaturization and improvements in sensor capabilities have provided opportunities for alternative measurement systems for GLOBE. A comparison of new sensors and existing GLOBE instruments with research-grade instruments at the NASA Langley Chemistry and Physics Atmospheric Boundary Layer Experiment (CAPABLE) site co-located with Virginia Department of Environmental Quality (VA DEQ) air-monitoring station is presented.

Aerosols

Aerosols are small particles that can remain suspended in the atmosphere for a period of time. The GLOBE aerosols protocol utilizes a passive handheld remote-sensing sun photometer to measure Aerosol Optical Depth (AOD)—how much of the sun's light is scattered or absorbed by aerosols. The GLOBE sun photometer performs well, however manufacturing constraints make it difficult for GLOBE schools to participate in the aerosols protocol. In continuation from the summer of 2013, the Solar Handheld Aerosol Determination Equipment (SHADE) spectrophotometer was tested to determine its potential as an alternate GLOBE instrument.

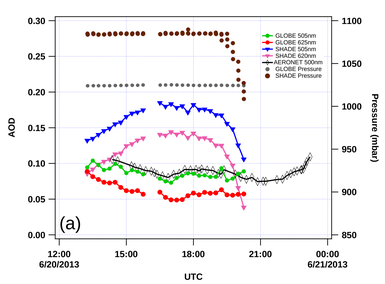
-(L) the SHADE spectrophotometer utilizes photodiodes to measure a voltage which is then used to calculate AOD on-board. http://shade.ubicode.com/

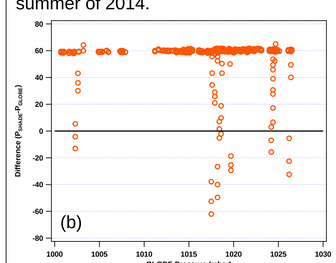
-(R) & (1) the GLOBE sun photometer utilizes light emitting diodes to measure voltage which is recorded and used to calculate AOD.

Summer 2013

During the summer of 2013, over 1200 side-by-side column measurements of AOD were taken with the GLOBE and SHADE photometers. The results were compared to each other and to AOD readings from AERONET at the CAPABLE site. This research resulted in inconsistent SHADE measurements. An investigation yielded a comparison between on-board readings of pressure from SHADE and data gathered at the CAPABLE site.

While the CAPABLE measurements ranged from 1000.7-1026.5 mbar, SHADE's readings ranged from 955.5-1089.7 mbar and became erratic as the batteries began losing charge (b). The analysis of potential causes for the inconsistent data continued through the summer of 2014.

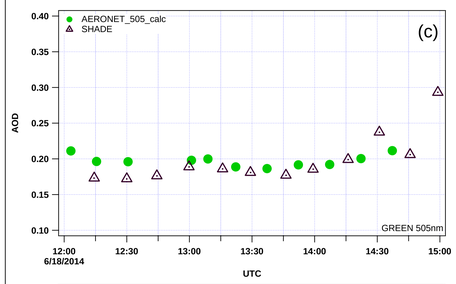


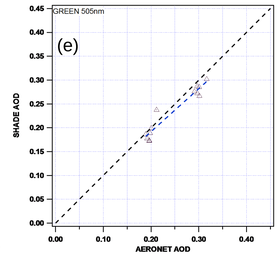


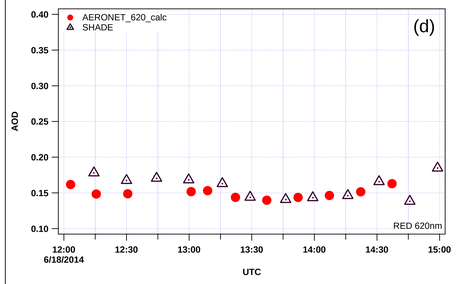
-(a) Example results display that although GLOBE remained consistent with AERONET, SHADE measurements were inconsistent.

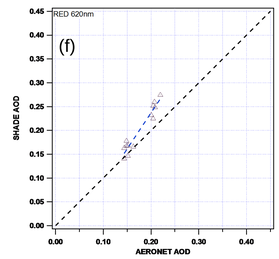
-(b) The difference between SHADE and GLOBE pressure data displays the rapidly decreasing SHADE measurements.

Comparing SHADE and AERONET









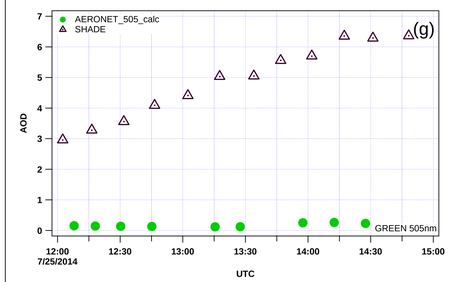
Promising Results

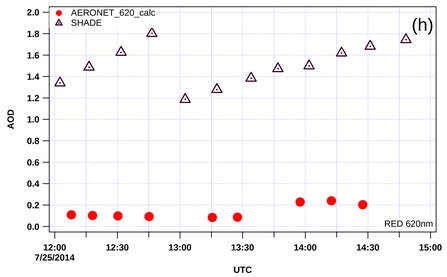
SHADE data gathered from the beginning of the summer looked promising (c) - (f). Similar to 2013, the on-board pressure readings were significantly higher than CAPABLE measurements. The calculated AOD compared nicely to AERONET nonetheless.

Stronger communication with the SHADE manufacturers led to efficient trouble-shooting of the supplemental software. Comprehensive column headings were added based on feedback. Date and time format was unusable without a decoder however.

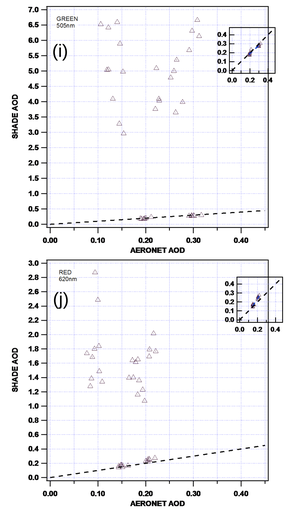
Early concerns included the small field of view (aperture) and off-centered design which caused difficulties in stabilizing the alignment in order to make measurements. Additionally, scratches on the plastic cover for the apertures caused skepticism with manufacturing quality control and precision.

Inconsistent Results

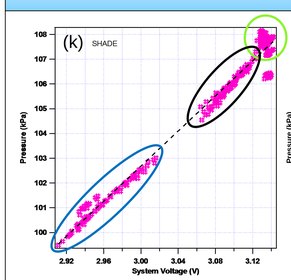


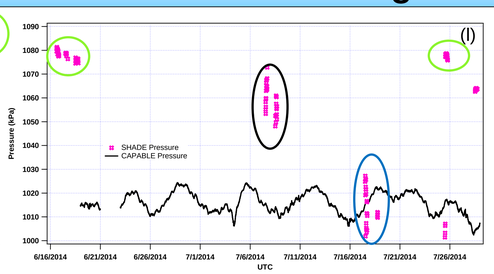


Upon continuing data collection after approximately two weeks of unsuitable weather conditions, the AOD values appeared unreasonably higher than those recorded through AERONET. The batteries were replaced on the twenty-fifth of July - shown above in plots (g) & (h). Although the time of the battery replacement is visible in the red wavelength (h), the high AOD values continue through the end of the day and into future readings.

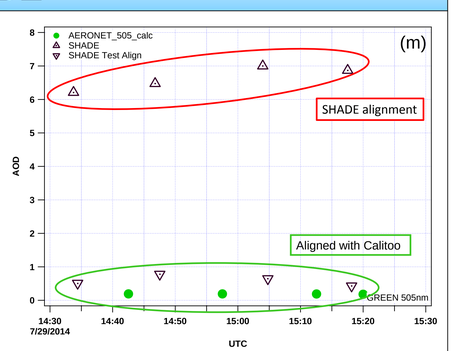


Troubleshooting SHADE





Speculation resumed with the correlation between the pressure readings and battery voltage within the instrument. Prior to the batteries losing charge, the pressure recorded by SHADE remained a consistent sixty millibar higher than the research grade measurements from the adjacent CAPABLE. A shocking correlation between the system voltage and pressure measurements was observed (k). However, an unreliable pressure sensor was not the only cause of unpredictable AOD data. The time series plots corresponding to the pressure readings outlined in green are displayed above (c),(d),(g),(h), & (l).



A subsequent experiment exposed another potential cause for the inconsistent recordings of AOD. An approximate alignment with the sun using another handheld photometer displays far more reasonable AOD values (m).

Calculating AOD for GLOBE

The formulas below are used to calculate AOD from the voltage readings produced by the GLOBE photometer.

$$AOD = \frac{[\ln(V_o/R^2) - \ln(V-V_{dark}) - a_r (p/p_o)m]}{m}$$

$$R = \frac{(1-\varepsilon^2)}{[1+\varepsilon \cos(360^0 \bullet d/365)]}$$

V_o= Calibration constant for each channel
R= Earth-Sun distance
Ɛ= Eccentricity
d= Day of year (Julian Day)
V= Voltage readings obtained with photometer
V_{dark}= Dark voltage readings obtained with photometer
a_r= Rayleigh scattering coefficient for each channel
P=Pressure at location and time of readings
P_o= Standard sea-level atmospheric pressure
m= air mass

Conventionally, air mass is defined as the secant of the solar elevation angle, however in 1994, Andrew Young derived a more accurate formula to be used for calibration. His formula proves to be more accurate than others at large zenith angles (Young 1994).

$$m(z) = \frac{1.002432\cos^2 z + 0.148386\cos z + 0.0096467}{\cos^3 z + 0.149864\cos^2 z + 0.0102963\cos z + 0.000303978}$$

The solar zenith angle is the complimentary angle to the solar elevation angle which can be calculated by the equation below.

$$\sin\theta_s = \cosh \cos\delta \cos\Phi + \sin\delta \sin\Phi$$

Where $\boldsymbol{\theta_s}$ is solar elevation angle, $\boldsymbol{h}$ is the hour angle, $\boldsymbol{\delta}$ is solar declination, and $\boldsymbol{\Phi}$ is the latitude at the measurement site.

Lunar Photometer

In addition to the inter-comparison of SHADE, GLOBE and AERONET, a lunar photometer was installed at the CAPABLE site. While AERONET tracks the sun throughout the day, this lunar photometer is one of the first instruments to utilize the moon in collecting AOD data overnight. The appearance and functionality of the equipment compares closely to AERONET, so the instillation process was nearly identical. Measurements were taken this past summer throughout two two-week periods in accordance with the lunar cycle.

References & Acknowledgements

Eck, T. F., B.N.Holben, J.S.Reid, O.Dubovik, A.Smirnov, N.T.O'Neill, I.Slutsker, and S.Kinne. "Wavelength dependence of the optical depth of biomass burning, urban, and desert dust aersols." *Journal of Geophysical Research* 104.D24 (1999). Web.
Young, Andrew T. "Air mass and refraction." *Applied Optics* 33.6 (1994). Web.

The author would like to thank Dr. Margaret Pippin, Mr. Timothy Berkoff, and Dr. Ali Omar. Additionally, this project would not have been possible without the support of the NASA Langley Aerospace Research Student Scholars (LARSS) Program. This work was supported by the Long-term Engagement in Authentic Research with NASA (LEARN) project, GLOBE, and TEMPO Student Collaboration with funding provided through NASA SMD.